Comparison of Susceptibility of Pest *Euschistus servus* and Predator *Podisus maculiventris* (Heteroptera: Pentatomidae) to Selected Insecticides

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ABSTRACT Susceptibility of the brown stink bug, *Euschistus servus* (Say), and the spined soldier bug, *Podisus maculiventris* (Say), to acetamiprid, cyfluthrin, dicrotophos, indoxacarb, oxamyl, and thiamethoxam, was compared in residual and oral toxicity tests. Generally, susceptibility of *P. maculiventris* to insecticides was significantly greater than or not significantly different from that of *E. servus*. Cyfluthrin and oxamyl were more toxic to the predator than to *E. servus* in residual and feeding tests, respectively. Dicrotophos is the only compound that exhibited both good residual and oral activity against *E. servus*, but even this toxicant was more toxic to the predator than to the pest in oral toxicity tests. Feeding on indoxacarb-treated food caused high mortality for both nymphs and adults of *P. maculiventris*. In contrast, *E. servus* was unaffected by feeding on food treated with this compound. Insecticide selectivity to *P. maculiventris* was detected only with acetamiprid for adults in residual toxicity tests and for nymphs in oral toxicity tests. Because insecticide selectivity to *P. maculiventris* was limited, it is extremely important to conserve *P. maculiventris* in cotton fields by applying these insecticides for control of brown stink bugs only when the pest reaches economic threshold.

KEY WORDS *Euschistus servus*, *Podisus maculiventris*, insecticide susceptibility

STINK BUGS HAVE BEEN REPORTED as pests of cotton since the beginning of the 20th century (Morrill 1910). However, because use of broad-spectrum insecticides has diminished due to successful eradication of the boll weevil, use of *Bacillus thuringiensis* (Bt) cotton, and development of new selective insecticides, stink bugs have emerged as pests of increasing importance (Greene and Turnipseed 1996). In 2002, stink bugs were responsible for an estimated $3.4 million in costs associated with crop loss and insecticide costs across the United States (Williams 2003). The southeastern states had the highest losses to stink bugs. The most important stink bug pests in the southeast are the southern green stink bug, *Nezara viridula* (L.); the green stink bug, *Acrosternum hilare* (Say); and the brown stink bug, *Euschistus servus* (Say) (Roach 1988). Stink bugs feed on developing seeds and lint (Barbour et al. 1990) causing shedding of newly formed bolls, yellowing of lint, and reduction in yields (Wene and Sheets 1964, Roach 1988, Greene et al. 1999, Williams 2003, Willrich et al. 2003).

The spined soldier bug, *Podisus maculiventris* (Say), feeds on a variety of insect prey, including nymphs and adults of stink bugs in a diversity of crop and noncrop ecosystems (Jones 1918, McPherson 1980, McPherson et al. 1982). *P. maculiventris* usually occurs concurrently with *E. servus* in corn, cotton, soybean, and peanuts (P.G.T., unpublished data), so chemical interventions for control of the pest may be potentially hazardous to the predator. Thus, insecticide selectivity to this natural enemy is an important issue in integrated pest management (IPM) of *E. servus.*

Dicrotophos is the standard organophosphate used for control of *N. viridula, A. hilare,* and *E. servus* in cotton. Other organophosphates such as methyl parathion and acephate also are being used for control of stink bugs. The pyrethroids cyfluthrin, bifenthrin, zetacypermethrin, and lambda-cyhalothrin can provide control, depending on the stink bug species. Toxicity of these insecticides to stink bugs has been demonstrated in topical and residual studies in the field and laboratory (McPherson et al. 1979; Emfinger et al. 2001; Greene et al. 2001; Greene and Capps 2002; Ngo et al. 2002; Willrich et al. 2002a,b,c).

Indoxacarb, acetamiprid, and thiamethoxam are three new compounds that target plant feeding pests. Indoxacarb is a new oxadiazine insecticide that is active on foliar feeding lepidopteran larvae (Wing et al. 2000). When the larvae ingest sprayed foliage or are sprayed directly, they stop feeding and either go into mild convulsions or a passive paralysis from which there is no recovery. Acetamiprid is a new systemic

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insecticide belonging to the neonicotinoid family. It acts on the central and peripheral nervous system, causing irreversible blocking of the postsynaptic nicotinergic acetylcholine receptors (Bai et al. 1991). As with nicotine, binding to these receptors results in excitation and paralysis, followed by death. This insecticide has excellent systemic and translaminar properties and high residual activity (Takahashi et al. 1992) and thus is particularly effective in controlling small plant-sucking pests such as whiteflies, aphids, and plant bugs. Thiamethoxam is a second generation neonicotinoid compound with contact and ingestion activity for many important sucking pests such as whiteflies, aphids, thrips, and plant bugs (Mason et al. 2000). Like acetamiprid, it interferes with the nicotinic acetylcholine receptors in the nervous system of the insect (Maienfisch et al. 2001).

Insecticide susceptibility varies among species of stink bugs. Generally, *E. servus* are less susceptible to pyrethroids, except for bifenthrin, and more susceptible to bifenthrin and acephate than *N. viridula* and *A. hilare.* Emfinger et al. (2001) and Willrich et al. (2002a) reported that cypermethrin, lambda-cyhalothrin, and cyfluthrin were significantly more toxic to *N. viridula* compared with *E. servus,* whereas bifenthrin and acephate were more toxic to *E. servus* compared with *N. viridula* in residual toxicity tests. Topical applications of zetacypermethrin and cyfluthrin were more toxic to *N. viridula* and *A. hilare* adults than to *E. servus* adults (Greene et al. 2001, Greene and Capps 2002). In aerial applications in large field plots, McPherson et al. (1979) demonstrated that *Edessa bifida* (Say) adults were significantly more tolerant to methyl parathion compared with *A. hilare, N. viridula, E. servus,* and *Euschistus tristigmus* (Say), all of which were equally susceptible to this insecticide.

There are three general techniques used for determining the toxicity of insecticides to natural enemies: 1) topical application of the insecticide on the insect, 2) exposure of the insect to dried residues of the insecticide applied to a substrate or plant part, and 3) monitoring natural enemy populations before and after applications of insecticides in the field. All three techniques provide valuable information on expected and observed impact of these insecticides on natural enemies in the field. Because novel insecticides with ingestion activity have been discovered, techniques need to be designed to determine the toxicity of an insecticide ingested by an insect. Many studies have used the first three methods to determine the effect of insecticides on various species of stink bug pests (Emfinger et al. 2001; Greene et al. 2001; Greene and Capps 2002; Ngo et al. 2002; Willrich et al. 2002a,b,c) and *P. maculiventris* (McPherson et al. 1979, Wilkinson et al. 1979, Yu 1988, Boyd and Boethel 1998). A single study has examined the effect of feeding on insecticides on the predatory stink bug (Mohaghegh et al. 2000), and none have been conducted with pest stink bugs. The goal for this research was to compare the susceptibility of *E. servus* and *P. maculiventris* nymphs and adults to acetamiprid, cyfluthrin, dicrotophos, indoxacarb, oxamyl, and thiamethoxam in both residual and oral toxicity tests.

Materials and Methods

Insects. *E. servus* and *P. maculiventris* colonies that originated from adults collected from cotton in Irwin County, Georgia, in 2002 were reared in an environmental chamber at 27°C, 60% RH, and a photoperiod of 14:10 (L:D) h. Brown stink bugs were fed raw, shelled peanuts, *Arachis hypogaea* L., and pole beans, *Phaseolus vulgaris* L., whereas *P. maculiventris* were fed fourth instars of fall armyworm, *Spodoptera frugiperda* (J.E. Smith). First and second generation third instars (≈24 h after ecdysis) and 3- to 6-d-old females of *P. maculiventris* and *E. servus* were used in toxicity tests.

Insecticides. Doses of each insecticide used in these experiments simulated the concentrations of field-use rates based on applications at a total volume of 93.5 liters/ha. The test included the following six treatments and rates: 1) acetamiprid (Assail 70 [577 μg/ml], Cerexagri, Inc., King of Prussia, PA), 2) cyfluthrin (Baythroid 2 [346 μg/ml], Bayer Corp., Atlanta, GA), 3) dicrotophos (Bidrin 8 [3,806 μg/ml], Amvac, Los Angeles, CA), 4) indoxacarb (Steward 1.25 [1,038 μg/ml], DuPont, Wilmington, DE), 5) oxamyl (Vydate 2 [2,883 μg/ml], DuPont), and 6) thiamethoxam (Centric 25 [715 μg/ml], Syngenta, Greensboro, NC). Water was used for a control.

Residual Toxicity. In residual tests, an insecticide treatment was sprayed on the top and bottom of a new plastic petri dish (100 by 15 mm) by using a Preval sprayer (Precision Valve Corp., Yonkers, NY) and allowed to dry for 1 h. Then, *E. servus* nymphs were placed singly in treated petri dishes. A randomized complete block design was used with five insects per block for eight blocks (40 insects per treatment). Insects were not fed during the test to avoid the possibility of the insects feeding on contaminated food. After a 24-h exposure, insects were moved to clean petri dishes and provided food and water. Mortality of the insects was recorded at 24-h intervals for 96 h after exposed to residues of the insecticide treatments. The whole procedure was repeated for *E. servus* adult females and *P. maculiventris* nymphs and adult females. If insects were unable to right themselves when turned on their backs, they were considered to be dead.

Oral Toxicity. Oral toxicity was tested by allowing insects to feed on insecticide-treated food, newly shelled pole beans for *E. servus* and freshly killed (frozen for 1 h) fourth instars of *S. frugiperda* for *P. maculiventris.* Before the test, food was dipped and held in an insecticide treatment for 30 s and placed on a wire screen for 1 h to allow the chemical to dry. After the materials dried, treated food was wrapped in Parafilm to eliminate the possibility of the insects being exposed to residues of the compound while feeding. Then, *E. servus* nymphs were placed singly in the petri dishes with treated food. A randomized complete block design was used with five insects per block

Table 1. Least squares means for percentage of mortality 1 and 4 d after treatment for *P. maculiventris* and *E. servus* nymphs and adults exposed to residues of acetamiprid, dicrotophos, cyfluthrin, indoxacarb, oxamyl, and thiamethoxam

Species	Insecticide	μg/ml	% Mortality 1 d after treatment		% Mortality 4 d after treatment	
			Nymphs	Adults	Nymphs	Adults
P. maculiventris	Dicrotophos	3806	100.0xa1A	75.0ya2B	100.0xa1A	100.0xa1A
	Oxamyl	2883	87.5xab1A	50.0yb1B	100.0xa1A	92.5xab1A
	Cyfluthrin	346	32.0yc1A	45.0yb1A	100.0xa1A	80.0xb1B
	Thiamethoxam	715	75.0xb1A	25.0yc1B	77.5xb1A	62.5xc1B
	Acetamiprid	577	32.5xc1A	0xd2B	45.0xc1A	12.5xd2B
	Indoxacarb	1038	0xd1A	0xd1A	0xd1A	0xd1A
	Control		0xd1A	0xd1A	0xd1A	0xd1A
E. servus	Dicrotophos	3806	100.0xa1A	100.0xa1A	100.0xa1A	100.0xa1A
	Oxamyl	2883	100.0xa1A	25.0ybc2B	100.0xa1A	97.5xa1A
	Cyfluthrin	346	22.5yc1A	32.5yb1A	75.0xb2A	62.5xb2A
	Thiamethoxam	715	40.0yb2A	10.0yde2B	80.0xb1A	75.0xb1A
	Acetamiprid	577	35.0xbc1A	15.0ycd1B	40.0xc1A	35.0xc1A
	Indoxacarb	1038	0xd1A	0xe1A	0xd1A	0xd1A
	Control		0xd1A	0xe1A	0xd1A	0xd1A

Least squares means within a row followed by the same lowercase letter (x–y) are not significantly different between days after treatment for a single species, developmental stage, and insecticide. Least squares means within a column followed by the same lowercase letter (a–e) are not significantly different between insecticides for a single species, developmental stage, and time after treatment. Least squares means within a column followed by the same number are not significantly different between species for a single insecticide, developmental stage, and time after treatment. Least squares means within a row followed by the same capital letter are not significantly different between insect developmental stages for a single species, insecticide, and time after treatment. (PROC MIXED, LSD, $P > 0.05$, $n = 40$, SE = 0.028, df = 84).

for a total of eight blocks (40 insects per treatment). Feeding by these insects was observed continuously for 6 h and recorded. Timing of the feeding began upon the first occurrence of feeding. Mortality was recorded at 24-h intervals for 96 h after the insects fed on treated food. The whole procedure was repeated for *E. servus* adult females and *P. maculiventris* nymphs and adult females.

Statistical Analysis. Percentage of mortality data for residual and oral toxicity experiments were analyzed using PROC MIXED (SAS Institute 1999). Fixed effects were species, stage, insecticide, and day. Random effects were blocks within species and stage; randomized complete block error by insecticide within species and stage pooled over time; petri dishes within species, stage, block, and insecticide; block by day within species and stage; randomized complete block error by day within species; and stage and residual error. A reduced model without petri dishes and day was used to analyze mean insect feeding times. Least squares means were separated by least significant difference (LSD) (SAS Institute 1999) where appropriate.

Results

Residual Toxicity. A significant species, stage, insecticide, and day interaction was detected for percentage mortality data in residual tests ($F = 2.48$; df = 24, 672; $P = 0.0001$). Overall, residues of dicrotophos and oxamyl were highly toxic, cyfluthrin was highly to moderately toxic, thiamethoxam and acetamiprid were moderately toxic, and indoxacarb was nontoxic to both insect species (Table 1). For nymphs and adults of both species, cyfluthrin caused significantly higher mortality 4 d after treatment compared with 1 d after treatment, suggesting that this insecticide slowly kills the insects. For nymphs, toxicity of dicrotophos, oxamyl, and thiamethoxam (*P. maculiventris* only) was greater than that for all other insecticides by 1 d after treatment and did not increase from 1 to 4 d after treatment, indicating that these insecticides killed the insects quicker than the other insecticides. Exposure to residues of dicrotophos caused significantly greater mortality compared with oxamyl for *E. servus* and *P. maculiventris* adults 1 d after treatment corroborating the finding of Greene and Capp (2003) that brown stink bugs were more susceptible to dicrotophos than oxamyl in topical bioassays. Differences in swiftness of response of insects to insecticides should be examined during comparisons of insecticide susceptibility because this information possibly could be used in predicting potential field effectiveness of insecticides. For example, using this difference in response time detected between dicrotophos and oxamyl for *E. servus* adults in the laboratory, we could hypothesize that dicrotophos could be more successful than oxamyl in reducing internal damage to cotton bolls by this pest in the field.

By 4 d after treatment, both insect species responded similarly to dicrotophos, oxamyl, thiamethoxam, and indoxacarb in residual toxicity studies (Table 1). However, cyfluthrin residues were more toxic to *P. maculiventris* than to *E. servus* nymphs and adults. Other researchers have reported that susceptibility to cyfluthrin was higher for *N. viridula* and *A. hilare* than for *E. servus* (Emfinger et al. 2001, Greene et al. 2001, Greene and Capps 2002). Acetamiprid, however, was less toxic to *P. maculiventris* than *E. servus* adults, even though for both species the toxicity of the insecticide was relatively low compared with that of the other insecticides with residual activity.

Comparisons between nymphs and adults revealed that there were no significant differences in toxicity of residues between *E. servus* nymphs and adults for each insecticide by 4 d after treatment (Table 1). In con-

Table 2. Least squares means for percentage of mortality 4 d after treatment for *P. maculiventris* and *E. servus* nymphs and adults ingesting residues of acetamiprid, dicrotophos, cyfluthrin, indoxacarb, oxamyl, and thiamethoxam

Species	Insecticide	μg/ml	% Mortality 1 d after treatment		% Mortality 4 d after treatment	
			Nymphs	Adults	Nymphs	Adults
P. maculiventris	Indoxacarb	1038	97.5xa1A	27.5yb1B	97.5xa1A	87.5xa1B
	Dicrotophos	3806	95.0xa1A	45.0xa1B	95.0xa1A	50.0xb1B
	Thiamethoxam	715	65.0xb1A	10.0xc1B	70.0xb1A	17.5xc1B
	Oxamyl	2883	40.0yc1A	0xd1B	50.0xc1A	0xd1B
	Acetamiprid	577	15.0xd2A	0xd1B	15.0xd2A	7.5xd1A
	Cyfluthrin	346	0xe1A	0xd1A	5.0xe1A	2.5xd1A
	Control		0xe1A	0xd1A	0xe1A	0xd1A
E. servus	Dicrotophos	3806	47.5xa2A	0xa2B	77.5xa2A	0xa2B
	Acetamiprid	577	25.0yb1A	0xa1B	40.0xb1A	0xa1B
	Thiamethoxam	715	10.0yc2A	0xa2B	25.0xc2A	5.0xa2B
	Cyfluthrin	346	2.5xc1A	0xa1A	7.5xd1A	5.0xa1A
	Oxamyl	2883	0xc2A	0xa1A	2.5xd2A	0xa1A
	Indoxacarb	1038	0xc2B	7.5xa2A	2.5xd2A	7.5xa2A
	Control		0xc1A	0xa1A	0xd1A	0xa1A

Least squares means within a row followed by the same lowercase letter (x–y) are not significantly different between days after treatment for a single species, developmental stage, and insecticide. Least squares means within a column followed by the same lowercase letter (a–e) are not significantly different between insecticides for a single species, developmental stage, and time after treatment. Least squares means within a column followed by the same number are not significantly different between species for a single insecticide, developmental stage, and time after treatment. Least squares means within a row followed by the same capital letter are not significantly different between insect developmental stages for a single species, insecticide, and time after treatment.

trast, residues of cyfluthrin, thiamethoxam, and acetamiprid were more toxic to *P. maculiventris* nymphs than to adults, whereas dicrotophos and oxamyl were equally toxic to these two developmental stages.

Oral Toxicity. Factorial analysis revealed that there was a significant species, stage, insecticide, and day interaction for percentage of mortality data in oral toxicity tests ($F = 8.98$; df = 24, 672; $P = 0.0001$). For *P. maculiventris,* percentage of mortality that resulted from feeding on food treated with dicrotophos, indoxacarb, thiamethoxam, and oxamyl was not significantly different between day 1 and 4 after treatment except for adults feeding on indoxacarb residues (Table 2). These results suggest that for insecticides with feeding activity against this predator, mortality occurred relatively quickly. In contrast, for brown stink bug adults, mortality caused by feeding on dicrotophos, acetamiprid, and thiamethoxam was higher for day 4 compared with day 1 after treatment. We conclude that it took dicrotophos and thiamethoxam longer to kill the pest compared with the predator, and this was one indication that the predator was more susceptible to these insecticides than the pest.

Nymphs were more susceptible to insecticides than adults for both insect species 4 d after treatment (Table 2). Except for cyfluthrin, which was nontoxic to *E. servus* and *P. maculiventris,* each pentatomid species responded differently to insecticides in these tests. For *P. maculiventris,* indoxacarb and dicrotophos (nymphs only) caused significantly greater mortality than the other insecticides. Thiamethoxam and oxamyl were moderately toxic to *P. maculiventris* nymphs compared with the other insecticides. For brown stink bugs, dicrotophos (nymphs only) caused significantly greater mortality than the other insecticides, thiamethoxam (nymphs only) was the least toxic insecticide among all the toxicants, and oxamyl and the control treatment (water) did not result in significantly different percentages of mortality.

Generally, by 4 d after treatment, *P. maculiventris* was more susceptible than *E. servus* to the insecticides that exhibited ingestion activity (Table 2). However, acetamiprid was more toxic to *E. servus* than to *P. maculiventris* nymphs, even though for both species the toxicity of the insecticide was relatively low compared with that of the other insecticides. For nymphs and adults, dicrotophos was more toxic to *P. maculiventris* than to *E. servus* in feeding tests. Another organophosphate, methyl parathion, has been reported to be more toxic to *P. maculiventris* compared with *E. servus* (McPherson et al. 1979). The greatest difference in insecticide susceptibility between *P. maculiventris* and *E. servus* occurred for indoxacarb. *P. maculiventris* nymphs and adults were highly susceptible to indoxacarb when feeding through dried residues of the insecticide on *S. frugiperda* larvae. In contrast, feeding on indoxacarb-treated shelled pole beans had little adverse effect on *E. servus.* This higher susceptibility to indoxacarb for *P. maculiventris* compared with the brown stink bug may be due to differences in surface humidity on treated food. Humidity can affect the mortality of insects feeding on indoxacarb-treated food, for higher mortality occurred for *L. lineolaris* and *Geocoris punctipes* (Say) feeding on cotton in plant cages with high relative humidity compared with those with low relative humidity (Tillman et al. 2001). It is possible that the surface humidity of insecticide-treated prey for the predator could be higher than that for insecticide-treated pole beans fed to brown stink bugs. Future experiments will be conducted to study the effect humidity may have on susceptibility of these insects feeding on indoxacarb-treated food.

Table 3. Least squares means for average feeding time for *P. maculiventris* and *E. servus* ingesting residues of acetamiprid, dicrotophos, cyfluthrin, indoxacarb, oxamyl, and thiamethoxam

Species	Insecticide	μg/ml	Ave. feeding time (min)
P. maculiventris[a]	Control		118.33a
	Cyfluthrin	346	135.32a
	Indoxacarb	1038	74.77b
	Oxamyl	2883	63.86b
	Acetamiprid	577	32.83c
	Dicrotophos	3806	19.09c
	Thiamethoxam	715	12.93c
E. servus	Control		71.11a
	Indoxacarb	1038	41.08b
	Cyfluthrin	346	30.71b
	Oxamyl	2883	22.41b
	Dicrotophos	3806	8.60bc
	Acetamiprid	577	5.73c
	Thiamethoxam	715	5.67c

Least squares means within a column followed by the same letter are not significantly different between insecticides for a single species (PROC MIXED, LSD, $P > 0.05$, $n = 40$, SE = 8.3, df = 84).

[a] Nymphs and adults combined.

The interaction between species and insecticide was significant for average time spent feeding on treated food ($F = 7.7$; df = 6, 168; $P = 0.0001$). For all insecticides, except cyfluthrin for *P. maculiventris,* feeding time was significantly lower than that for controls (Table 3). A reduction in feeding time indicated that the insecticides inhibited feeding. Because lowest feeding times occurred for insects feeding on dried residues of acetamiprid, dicrotophos, and thiamethoxam, these three toxicants inhibited feeding more than any of the other insecticides.

Discussion

The combination of residual and oral toxicity studies provided valuable information on the overall effectiveness of each insecticide against the pest stink bug *E. servus.* Our results are consistent with previous studies that showed that dicrotophos has excellent activity against *E. servus* in field, residual, and topical tests (Greene et al. 2001; Greene and Capps 2002; Willrich et al. 2002a, b). In addition, our study demonstrates that dicrotophos has ingestion activity, at least against nymphs, and inhibits feeding by this pest. Dicrotophos is the only compound that exhibited both good residual and oral activity against *E. servus,* and the dual activity of this insecticide against the pest may account for the reliable effectiveness of this toxicant in controlling this pest in producers' fields. Our results also are in agreement with previous studies that demonstrated that dicrotophos is more toxic than cyfluthrin to *E. servus* (Emfinger et al. 2001, Greene et al. 2001, Greene and Capps 2002). Because oxamyl exhibits only residual activity against *E. servus* and kills adults slower than dicrotophos, the former toxicant may be less effective than dicrotophos in controlling this pest in the field. However, in one field trial, percentage of boll damage by another stink bug pest, *N. viridula,* was low in both oxamyl- and dicrotophos-treated cotton plots (Greene and Herzog 2000). Field trials should be done to evaluate the effectiveness of this insecticide against *E. servus* in the cotton fields. In contrast to our results, Willrich et al. (2002b) reported that toxicity of thiamethoxam residues on cotton bolls was not significantly different than that for dicrotophos. However, Greene and Capps (2002) reported that thiamethoxam was highly toxic to *E. servus* immatures and moderately toxic to adults, whereas dicrotophos was highly toxic to both developmental stages in topical bioassays. Nevertheless, in field trials, this pesticide significantly reduced numbers of *E. servus* adults and immatures below the untreated check (Ngo et al. 2002). Our results on residual and oral toxicity of acetamiprid corroborate recent findings that this insecticide has little activity against *E. servus* in field, residual and topical tests (Greene and Capps 2002, Ngo et al. 2002, Willrich et al. 2002c). Indoxacarb, which exhibited no tarsal contact or ingestion activity against *E. servus* in our study, has been reported previously to have no impact on this pest in residual and topical bioassays (Greene and Capps 2002, Willrich et al. 2002b). In field tests in some locations, however, the number of adults of this pest in indoxacarb plots was significantly lower than that in the untreated controls (Ngo et al. 2002). The activity of this compound against brown stink bugs in this field test is difficult to explain, but it may be related to the effect of humidity on toxicity of this insecticide.

Because acetamiprid, indoxacarb, and thiamethoxam, which target plant-sucking insect pests caused little mortality for *E. servus* in oral toxicity experiments, it cannot be assumed that an insecticide with this mode of action will be lethal to all plant-feeding pests. However, the sublethal effects of these insecticides could have a positive economic impact on cotton production. For example, thiamethoxam, which strongly inhibited feeding by brown stink bugs, could possibly reduce percentage of damage to cotton bolls by this pest in the field.

P. maculiventris has been reported to be more susceptible to organophosphates than to first generation pyrethroids. Residues of the organophosphate methyl parathion were more toxic than those of the pyrethroid permethrin to adults of *P. maculiventris* (Boyd and Boethel 1998). A similar pattern for susceptibility of *P. maculiventris* adults and third instars to the organophosphates profenofos and sulprofos, and the pyrethroids permethrin and fenvalerate, occurred in residual studies conducted by Wilkinson et al. (1979). In our residual tests, however, differences in susceptibility between the organophosphate dicrotophos and the pyrethroid cyfluthrin occurred for adults, but not for nymphs.

Evaluation of the effects of directly or indirectly ingesting insecticides is essential to understanding the potential impact these insecticides could have on predators when these compounds are applied to cotton fields. Predators may ingest residues of insecticides during the following scenarios in the field: 1) feeding on plant tissue, pollen, or nectar contaminated with insecticide residues; 2) drinking rain water contaminated by insecticides; 3) feeding on systemic insecticides while sucking on plant sap; 4) preying on insects that have eaten foliage contaminated with insecticide residues; or 5) preying on insects contaminated with insecticide residues. A unique study evaluating the potential transfer of toxicity of certain insecticides from a prey species that consumed insecticides to the predator *G. punctipes* was conducted by Boyd and Boethel (1998). In these tests, most of the newer compounds such as spinosad were more selective than older compounds such as methyl parathion. In our study, however, one of the three newer compounds, indoxacarb, was equally as toxic to *P. maculiventris* nymphs as the older compound dicrotophos. Another new compound, thiamethoxam, was more toxic to *P. maculiventris* nymphs than oxamyl, and inhibition of feeding was greatest for thiamethoxam, acetamiprid, and dicrotophos for both insect species. Other studies have demonstrated that thiamethoxam has an adverse impact on predators in insecticide-treated cotton field plots (Gibson et al. 2003) and increases developmental time and reduces body weight of *Podisus nigrispinus* (Dallas) when nymphs are caged on cotton plants after application of the compound to the soil (Torres et al. 2003). Another novel study examining the impact of insecticides on *P. maculiventris* via ingestion was conducted by allowing individuals of this predator to drink water contaminated by insecticides (Mohaghegh et al. 2000). Fourth instars and adult females suffered the highest mortality when they ingested methomyl compared with the other insecticides. The pyrethroid deltamethrin was relatively safe for the predator in either stage, indicating again that carbamates are generally more toxic to *E. servus* than pyrethroids.

Studies comparing susceptibility of insecticides between natural enemies and their prey are vital for evaluating insecticide selectivity to natural enemies. In a novel study examining the selectivity of several insecticides to *P. maculiventris* and its lepidopteran prey, Yu (1988) determined that *P. maculiventris* adults were more susceptible to organophosphates and carbamates, but they were more tolerant of pyrethroids, compared with their lepidopteran prey. Our results demonstrated that generally, susceptibility of *P. maculiventris* to insecticides that exhibited residual or oral activity was greater than or not significantly different from that of *E. servus*. *P. maculiventris* was more susceptible than *E. servus* to cyfluthrin in residual tests and to oxamyl in feeding tests. Even dicrotophos, the insecticide most toxic to *E. servus*, was more toxic to the predator than to the pest in oral toxicity tests. Feeding on residues of indoxacarb resulted in high mortality for *P. maculiventris*, but *E. servus* was unaffected by feeding on residues of this toxicant. Therefore, an insecticide with ingestion activity against pests cannot be expected to have little impact on predators. Insecticide selectivity to *P. maculiventris* was detected only for acetamiprid for adults in residual toxicity tests and for nymphs in oral toxicity tests. Because insecticide selectivity to *P. maculiventris* was limited, it is extremely important to conserve *P. maculiventris* in cotton fields by applying these insecticides for control of brown stink bugs only when the pest reaches economic threshold. For the same reason, it is highly important that the insect species are correctly identified when whole plant scouting accompanies determinations of boll damage in assessing these economic thresholds.

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